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(19) (CA) **CANADIAN PATENT** (12)

(54) Pyrolysis Process

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No. OF CLAIMS 15

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This invention relates to a pyrolysis process for organic material using a fluidized bed reactor containing a suitable inert particulate solid. In particular, the process of the present invention relates to the conversion of an organic solid, for example, biomass, peat or coal into liquid, gas, and a char residue.

It is known to have a pyrolysis process using a fluidized bed reactor with a short reaction time at high temperatures ranging from 300°C to 1,000°C. Often, the reaction times are less than 5 seconds. It is also known to use an inert particulate solid within the reactor as a heat carrier to heat the organic material. The common products of pyrolysis are gases, liquids and a solid char. The inert particulate solid is usually sand or ash. In previous pyrolysis processes using fluidized bed reactors, the sand plus the char is transferred to a second fluid bed where the char is burned to heat the sand. The hot sand is then returned to the first fluidized bed reactor where the pyrolysis process is carried out, the hot sand heating the organic material. An embodiment of this process is described in United States Patent #3,853,498, issued December 10th, 1974 and naming R.C. Bailie as inventor. Pyrolysis processes which circulate the sand from one reactor to another can be expensive or difficult to operate on a continuous basis or inefficient.

It is an object of the present invention to provide a pyrolysis process that can be carried out efficiently on a batch or continuous basis in one reaction vessel without removing the sand from said vessel.

In accordance with the present invention, a pyrolysis process for organic material is used with a



fluidized bed reactor containing a suitable inert particulate solid and a bed to be fluidized. The reactor has a gas inlet and a gas outlet. Organic material is introduced into said reactor and a gas stream is introduced through said inlet to fluidize said bed and heat is introduced into said reactor. The inert material and organic material are sized relative to one another and the fluidized bed reactor is operated at a gas flow rate so that substantially all char resulting from the pyrolysis of the organic material is removed from the reactor by the gas stream through said gas outlet, but substantially all of the inert material remains in the reactor. The desired pyrolysis products so formed are then recovered.

Further, a reactor for use in a pyrolysis process in accordance with the present invention has a housing containing a suitable inert particulate solid material and a bed to be fluidized. There are means to introduce organic material into said reactor on a continuous basis and means to heat the reactor contents to decompose the organic material. The reactor has a gas inlet and a gas outlet and can be operated as a fluidized bed. The inert material and the organic material are sized relative to one another and the bed is operated at a suitable gas flow rate so that substantially all char resulting from the pyrolysis of the organic material will be removed from the reactor through the gas outlet but substantially all of the inert material will remain in the reactor.

In drawings which illustrate a preferred embodiment of the invention:

Figure 1 is a flow chart of one embodiment of a process in accordance with the present invention;

Figure 2 is a top view of a reactor in accordance

with the present invention;

Figure 3 is a sectional view of the reactor along the section A-A of Figure 1; and,

Figure 4 is a side view of the reactor of Figure 1.

Referring to the drawings in greater detail, the flow chart shown in Figure 1 is designed for the pyrolysis of poplar sawdust. The same flow chart could be used for pyrolysis of other materials. Substitution of components for those shown in the drawings, but within the scope of the attached claims, will be readily apparent to those skilled in the art.

In accordance with the process, a suitable inert particulate solid, for example, sand is located within the reactor. Particulate organic material is then fed into the reactor from a feeder. Gas is then passed through the reactor through a gas inlet and gas outlet to fluidize the bed. The inert material and the organic material are sized relative to one another and the fluidized bed is operated at a gas flow rate so that substantially all char resulting from the pyrolysis of the organic material is removed from the reactor by the gas stream through said gas outlet, but substantially all of the inert material remains in the reactor. Heat is introduced into the reactor by various means for example, the fluidizing gas can be preheated, or, heat can be introduced into the reactor through heat transfer surfaces within the bed, or, the organic material or the inert material can be preheated. Also, one or more of these means could be used simultaneously.

So long as substantially all of the char is removed from the reactor by the gas stream and substantially all of the inert material remains in the reactor, the relative particle sizes and the gas flow

rate can vary considerably. However, preferably the particle size and density of the inert material is such that it can be fluidized at a gas flow rate of at least 1.5 times the minimum fluidization velocity. Still  
5 more preferably, the particle size and density of the inert material is such that it can be fluidized in a range from 2 to 5 times the minimum fluidization velocity. Preferably, the gas velocity above the bed, in the freeboard zone, significantly exceeds the average  
10 terminal settling velocity of the organic particles.

Preferably the particle size of the inert material is approximately equal to or less than 1 mm and the particle size of the organic material is approximately equal to or less than 5 mm.

15 Preferably, the reactor is sized to give an apparent gas residence time ranging from 0.1 to 10.0 seconds. The process of the present invention can be carried out on a continuous basis or a batch basis. The reaction temperature preferably ranges from 300°C  
20 to 1,000°C. The operating pressure can vary over a wide range, as desired, but operation near atmospheric pressure is simple and produces acceptable results. In some instances, it may be preferable to have an inert material that is catalytically active in the reaction.  
25 In other words, even though the inert material is not consumed by the reaction, it acts as a catalyst in promoting the reaction.

After the pyrolysis products (ie. gas, including the char) leave the gas outlet of the reactor,  
30 they can be treated in various ways to recover the desired product or products. In the flow diagram shown in Figure 1, in one embodiment, the pyrolysis products are first passed into a hot cyclone in which the char is separated from the gas stream. The char

is removed from the cyclone into a char pot, where it can be used to provide heat for the reactor or be otherwise disposed of. The gas is then passed into a steam condenser or boiling water condenser where a tar product is removed. Next, the gas is passed through a cold water condenser where light organics and water are separated from the gas. After leaving the condenser, the gas is passed through a filter and, if necessary, through an adsorber. The purpose of the filter is to remove any solid or liquid impurities still remaining in the gas and the purpose of the adsorber is to recover volatile organic liquids. If the adsorber is not necessary, it can simply be by-passed or omitted. From the adsorber or, from the filter if the adsorber is not used, the gas is passed into a compressor and then a portion of the gas is drawn off as product gas while the balance is returned through a flow controller to the reactor to be used to fluidize the bed.

The product gases and vapours leaving the cyclone may be handled in any convenient conventional process unit for condensing liquids or for scrubbing out liquids. For example, instead of the surface condensers shown in Figure 1, liquid scrubbers could be used.

In addition to hot gas being re-cycled into the reactor through the gas inlet, as shown in Figure 3, hot gas can also be added to the organic feed at the point of injection as shown in Figure 1. While re-cycle gas is used in Figure 1, other gas could be used for the fluidizing gas as desired by those skilled in the art. As shown in Figures 2, 3 and 4, the reactor 2 is preferably cylindrical. The reactor has a cylindrical housing 4 with a flange 5 and L-shaped organic feed inlet 6. A bed 8 is located

near an end 10 of the reactor 2. Within the end 10, is a gas inlet 12. At an opposite end 14 is a gas outlet 16. The organic feed inlet 6 is arranged so that particulate organic material is fed into the reactor along its longitudinal axis with the feed inlet point 18 located within the fluidized bed 8. In some uses, it may be desired to have a reactor that is reduced in diameter in the freeboard zone in order to obtain higher gas velocities for transport of char particles through the gas outlet of the reactor.

So long as the particle size and density of the inert material are chosen so that it can be fluidized in an efficient manner by a fluidizing gas and, at the same time, the gas velocity in the freeboard above the fluid bed significantly exceeds the average terminal settling velocity of the organic particles, then the inert material will remain in the bed but the organic particles will be blown from the bed, especially as they lose mass due to the evolution of volatile vapours. In the result, it has been found that char will not accumulate in the fluid bed and there is no necessity to continuously remove and replace the inert material in order to remove or burn off the char. Also, it has been found that any unreacted solid feed will also be removed from the reactor by the gas stream.

Generally, it has been found that the ratio of re-cycle gas to product gas will vary from 6 to 20 depending on the operating velocity desired. This gas flow is high enough that most of the reaction heat can be supplied by heating the circulating gas to a temperature not too high above the reaction temperature. For example, for a reaction temperature of 500°C in one test, a temperature of 850°C for the fluidizing gas was adequate. A screw feeder was found to be suitable for

feeding the organic material into the reactor.

Yields of organic liquids from rapid pyrolysis of biomass organic material have been generally reported in the range from a few per cent to about 40% of the dry weight fed. Yields of organic liquids from biomass contained in the present invention can range from 45% of the dry weight fed from materials such as wheat straw to 65% for highly cellulosic materials such as hardwoods. Examples of organic materials that have been used with the process of the present invention are poplar wood and bark, aspen wood, maple wood and bark, peat, bagasse, wheat straw and corn stover. A number of coals have also been pyrolyzed by this process. The process is most successful with lower rank, non-caking coals. Generally, any organic material that is desired to be pyrolyzed, could be used with the process of the present invention. The organic material must, of course, be particulate and, preferably, the particle sizes should be approximately 1mm or less. Other materials, in addition to those mentioned herein, will be readily apparent to those skilled in the art.

As an example of the design criteria necessary for the successful operation of a process in accordance with the present invention, it is proposed to pyrolyze -30 mesh (595 $\mu$ m) diameter sawdust particles having 7% moisture content in a fluidized bed of sand. The fluidizing gas has a composition as set out in Table 2 below with an average molecular weight of 32.44. The reactor will operate at 500°C and slightly above atmospheric pressure at 110 kPa absolute. The char particles are assumed to have the same physical size as the sawdust feed particles but to be of lower density. From this information, the terminal settling velocity of the largest char particle can be calculated for



conditions in the reactor freeboard, using well known equations. Similarly, the terminal settling velocity of the smallest sand particle can be calculated.

- Typically, for particles of the same size, the difference in value of the terminal settling velocity for the two types of particles will be greater than a factor of ten. When superficial gas velocity (ie. the gas velocity at reactor conditions based on the empty reactor cross-section) is chosen between these two values, and the largest sand particle size is chosen so that the design velocity is at least 1.5 times the minimum fluidization velocity, the reactor will operate in accordance with the present invention. In this example, the process is carried out successfully using sand of -20 to +30 mesh (-841 to +595 $\mu$ m) with sawdust of -30 mesh size (-595 $\mu$ m) and a gas flow rate of 80 standard litres per minute in a temperature range from 450°C to 650°C. As a further example, the following results were obtained from one pyrolysis run:
- 20 Table 1 - Pyrolysis Run - Maple Sawdust Feed (-30 mesh size).

	Reactor Temperature	500°C
	Yield, % of sawdust fed	
	Gas	11.65%
25	Organic Liquid	61.96%
	Water	16.15%
	Char	8.89%
	Total Product Recovery	98.70%
	Vapour Residence Time	0.6 secs.
30	Fluidized Bed Solids-Ottawa sand -20 + 30 mesh.	

Table 2 - Breakdown of Gas Yields from Run of Table 1

Component	CO	CO <sub>2</sub>	H <sub>2</sub>	CH <sub>4</sub>	C <sub>2</sub> H <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>
Yield, % of Sawdust Fed	6.97	3.78	0.05	0.62	0.23	0.021

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A pyrolysis process for biomass for use with a fluidized bed reactor having a cylindrical housing containing a suitable inert particulate solid, and a bed to be fluidized, said reactor having a gas inlet and a gas outlet, with means to introduce biomass into said reactor on a continuous basis, said reactor having a feed inlet located to feed the biomass into the fluidized bed area of the reactor, between a base of said bed and said gas outlet, along a longitudinal axis thereof, said process comprising introducing particulate biomass into said reactor through said feed inlet, fluidizing said bed by introducing a gas stream through said gas inlet, introducing heat into said reactor, the inert material and biomass being sized relative to one another and the fluidized bed reactor being operated at a gas flow rate so that substantially all char resulting from the pyrolysis of the biomass is removed from the reactor by the gas stream through said gas outlet, but substantially all of the inert material remains in the reactor and recovering desired pyrolysis products so formed with liquid yields in excess of 45% of the dry weight fed, said process being carried out with an apparent gas residence time ranging from 0.1 to 10.0 seconds, with one reactor only, without recirculating any part of the particulate solid to a second reactor.
2. A pyrolysis process as claimed in Claim 1 wherein the particle size and density of the inert material is such that it can be fluidized at a gas flow rate of at least 1.5 times the minimum fluidization velocity.

3. A pyrolysis process as claimed in Claim 2 wherein the particle size and density of the inert material is such that it can be fluidized in a range from 2 to 5 times the minimum fluidization velocity.
4. A pyrolysis process as claimed in Claim 3 wherein the gas velocity above the bed significantly exceeds the average terminal settling velocity of the biomass.
5. A pyrolysis process as claimed in any one of Claims 1, 3 or 4 wherein the particle size of the inert material is approximately equal to or less than 1 mm.
6. A pyrolysis process as claimed in any one of Claims 1, 3 or 4 wherein the particle size of the biomass is equal to approximately 5 mm or less.
7. A pyrolysis process as claimed in any one of Claims 1, 2 or 3 wherein the process is carried out on a continuous basis.
8. A pyrolysis process as claimed in Claim 4 wherein after the gas outlet, treating the fluidizing gas in a gas-solid separating device, passing the gaseous stream to condensers or liquid scrubbers to remove organic liquid vapour from said gaseous stream.
9. A process as claimed in any one of Claims 1, 3 or 4 wherein the inert material is sand.
10. A process as claimed in any one of Claims 1, 3 or 4 wherein heat is introduced into the reactor by preheating the fluidizing gas.
11. A pyrolysis process as claimed in any one of Claims 1, 3 or 4 wherein heat is introduced into the reactor through heat transfer surfaces within the bed.
12. A pyrolysis process as claimed in any one of Claims 1, 3 or 4 where heat is introduced into the reactor by preheating the biomass.

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13. A pyrolysis process as claimed in any one of Claims 1, 3 or 4 wherein heat is introduced into the reactor by preheating the inert material.

14. A process as claimed in any one of Claims 1, 3 or 4 wherein the bed attains a reaction temperature ranging from 300°C to 1,000°C.

15. A pyrolysis process as claimed in any one of Claims 1, 3 or 4 wherein the inert material is catalytically active in the reaction.

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ABSTRACT OF THE INVENTION

A pyrolysis process for organic material uses a fluidized bed reactor containing sand as an inert material. Particulate organic material is introduced  
5 into the reactor together with a gas stream that is utilized to fluidize said bed. The sand particles and the organic material are sized relative to one another and the fluidized bed is operated at a gas flow rate so that substantially all char resulting  
10 from the pyrolysis of the organic material is removed from the reactor by the gas stream through the gas outlet. Substantially all of the sand remains in the reactor and the desired pyrolysis products so formed can be further processed for recovery. The sand can  
15 be heated by suitable heat transfer surfaces to provide heat for the reaction or reaction heat can be provided by treating the fluidizing gas, or both. A reactor for use in the process has a housing, a suitable inert particulate solid material contained therein together  
20 with a bed to be fluidized. The reactor has a gas inlet and a gas outlet with means to operate the fluidized bed. In previous pyrolysis processes for organic material, the inert material is removed to a second reaction vessel along with the char. In the  
25 second vessel, the char can be burned to heat the inert material and the inert material is then returned to the first reaction vessel. With the present invention, it is not necessary to remove the sand from the reaction vessel.

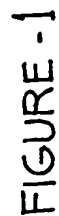
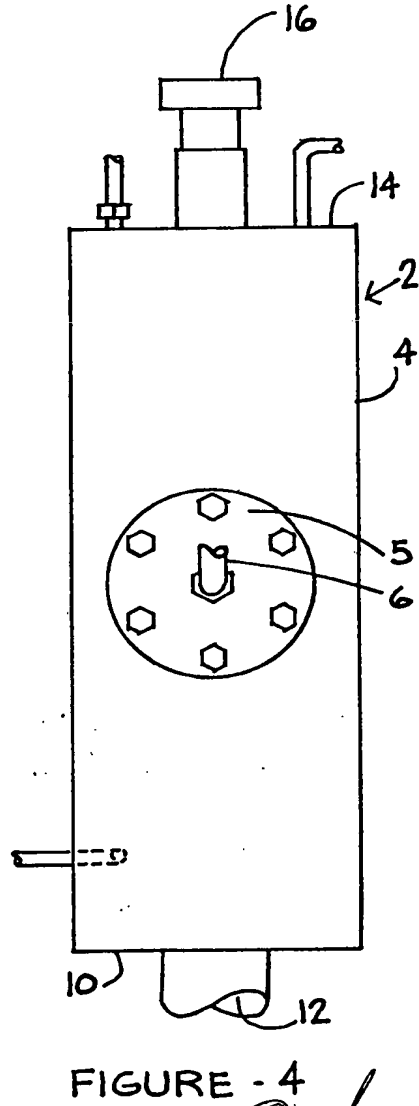
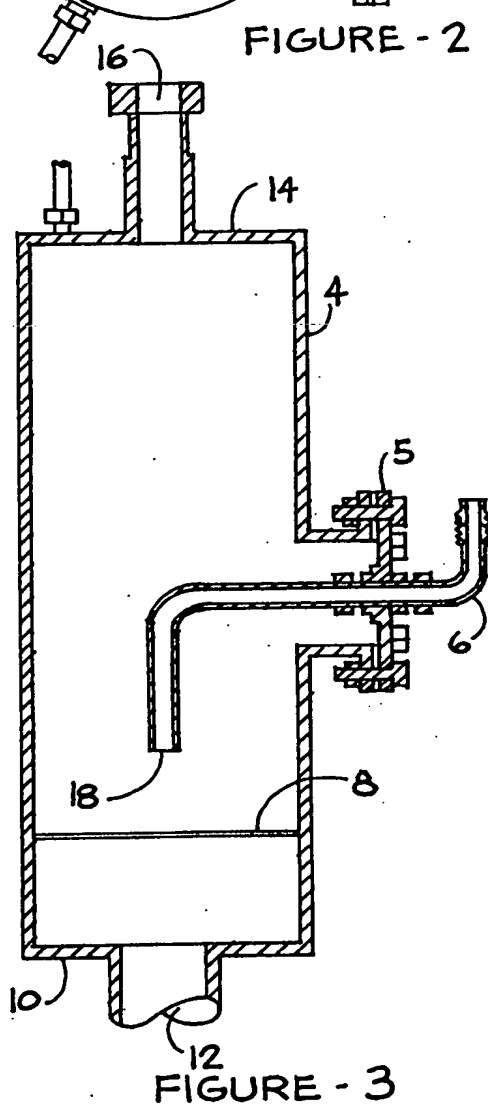
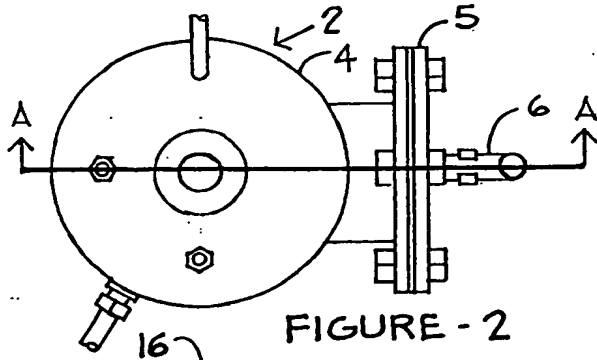


FIGURE - 1



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